Geomorphology And River Hydraulics of The Teton River

The construction and subsequent failure of Teton Dam in 1976 changed the physical and biological characteristics of the Teton River canyon for 17 river miles (RM) upstream from the dam site. This report documents the existing physical conditions and the changes that have occurred to the geomorphology and river hydraulics in the Teton River canyon as a result of the reservoir inundation and subsequent failure of Teton Dam.

Looking downstream at the borrow ponds and the remnants of Teton Dam.

What is the project background?

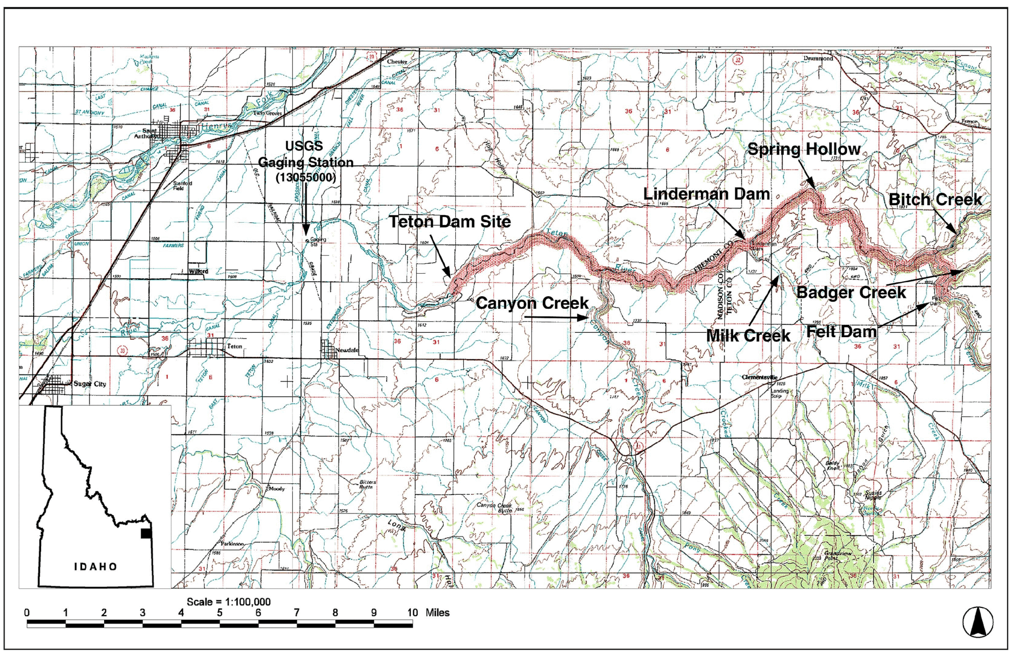
The construction of the Teton Basin Project, Lower Teton Division, was authorized by Public Law 88-583 on September 7, 1964. This project would have provided supplemental irrigation water for approximately 110,000 acres in the Fremont-Madison Irrigation District, for flood control operation, and for recreation and fish and wildlife mitigation measures (Schuster and Embree, 1980). The 17-mile-long reservoir was to have a total capacity of 288,000 acre-feet and a surface area of 2,100 acres.

Filling of the reservoir began October 3, 1975, and continued until June 5, 1976, when Teton Dam failed (Jansen, 1980). The reservoir was at elevation 5301.7, about 272 feet deep at the dam, and 22.6 feet below the planned maximum pool elevation when piping caused the embankment to fail. Approximately 250,000 acre-feet of water and 4 million cubic yards of embankment material were sent down the river in about 6 hours (Lloyd and Watt, 1981). The destruction downstream from the dam was extensive, reaching to the upper end of American Falls Reservoir, 95 miles downstream.

In addition to the devastation caused downstream, the portion of the Teton River canyon, which was inundated by the 17-mile-long reservoir, and Canyon Creek, a tributary 5 miles upstream of the dam which was inundated for 3 miles, were also affected. The initial filling of the reservoir and subsequent rapid drawdown triggered over 200 landslides in the canyon. The original river channel and terraces have been buried in localized areas by landslide debris. Currently, the river channel contains several long, slow velocity pools that are backed up by short, steep riffles or rapids formed from landslide debris. In addition to the reservoir-induced landslides, remnants of Linderman Dam and the submerged borrow pits upstream from Teton Dam have also impacted the slope of the river channel.

What is the purpose of studying the Teton River canyon?

As a result of the Teton Dam failure in 1976, different portions of the former reservoir inundation area have been affected in different ways. The objectives of this study are to document the current physical conditions (geologic, geomorphic, and hydraulic) of the Teton River in the former reservoir inundation area (Teton Dam site to the confluence with Bitch Creek) and changes that occurred from the filling of Teton Reservoir and subsequent failure of Teton Dam in 1976. The results from this study will provide information to assist in managing Reclamation withdrawn lands in and around the Teton River canyon upstream from the Teton Dam site. In addition, models developed from this study can be utilized as predictive tools for addressing various alternatives for modifying rapid and pool formations caused as a result of the dam failure.



Location map of study reach.

What types of data have been collected so far?

Data were collected in 1997, 1998, and 1999 along portions of the Teton River between the Teton Dam site and the Felt Dam Powerhouse, 19 river miles upstream. The data collected consist of new aerial and ground photographs, measurements of riverbed topography, water surface elevations, preliminary particle size analysis of landslide material, and bed-material particle size distributions. Additional data collected on water and air temperature, and the riparian vegetation community are described in separate reports (Bowser, 1999; Beddow, 1999).

Hydrographic data defining the water surface and channel bottom and limited topography data were collected for four reaches of river between the upstream extent of the reservoir inundation at the confluence with Bitch Creek (RM 17.2) and the Teton Dam site.

Areas of Hydrographic Data Collection

(1) The confluence with Bitch Creek to Spring Hollow (4 miles)
(2) Spring Hollow to the confluence with Canyon Creek (7 miles)
(3) A short reach at RM 4
(4) The borrow ponds (just over 1 mile)

The existing channel topography data, collected in 1997-99, were used to create a hydraulic model and a set of bathymetric maps for the Teton River pools from the confluence with Bitch Creek to the confluence with Canyon Creek and in the borrow ponds just upstream from the Teton Dam site. The maps document:

- The location of the measured data used to develop the maps
- The average daily discharge recorded at the time of the survey
- The mean measured water surface elevation of each pool during the survey
- The locations of cross sections used in the hydraulic model for this study

Particle size evaluation of landslide material was completed during the 1998 field investigations along the Teton River, but should be considered preliminary, due to the small data sample. The size of the landslide material on the valley floor and lower portion of the slopes ranges from silt to boulders greater than 10 feet across. Most of the material in the landslides consists of rock fragments from 3 inches to 3 feet across.

A previous study displayed all landslides on top of topographic contours developed in 1972 prior to the failure of Teton Dam (Magleby, 1981). To provide a new base map that represents existing topography in the canyon, a set of contour maps based on 2000 aerial photography is anticipated to be developed by the end of the year.

An example of an earthflow-type slide that occurred between Spring Hollow and Canyon Creek.

What was the extent of landslide activity in the Teton River canyon?

Landslide activity in the former reservoir area started with the filling of the reservoir (Reclamation, 1976). The June 5, 1976, dam failure activated more than 200 landslides along the reservoir rim, due to the filling and the rapid drawdown of the reservoir. Approximately 1,460 acres of canyon slopes were submerged by the reservoir, and 34 percent (500 acres) failed.

Approximately 3.6 million cubic feet of landslide debris moved downslope to the canyon floor, with some reaching and blocking the river. While a large amount of landslide debris reached the valley floor, much of the debris remained on the lower portion of the slopes.

Most of the landslides were shallow surface slumps, earth flows, debris flows, and rockfall. The thickness of the landslide debris ranged from less than 5 feet to about 25 feet normal to the slope.

Landslide activity has been an ongoing natural geomorphic process in the Teton River canyon ever since the placement of the Huckleberry Ridge tuff and uplift of the Rexburg Bench. These landslides have been naturally creating rapids and pools in the narrowest reaches of the Teton River canyon for thousands of years. For example, a debris flow that occurred during the last decade enhanced a major rapid and pool in the narrow reach between Badger Creek and Bitch Creek. This reach of the river is upstream from the area inundated by Teton Reservoir. However, fluvial processes have also been at work for thousands of years. This is why all the major rapids formed by prehistoric landslides have been reduced to small rapids and riffles.

Landslides in the Teton River Canyon are an integral part of the canyon evolution. The construction and failure of the Teton Dam have rapidly accelerated those processes in the portion of the river canyon below the high elevation of the former reservoir. The 1976 landslides also significantly reduced the volume of source material available (below the former reservoir level) for future landslides. Therefore, the probability and quantity of future landslides (initiated below the elevation inundated by the former reservoir) have been significantly reduced over the next several centuries to thousands of years.

The 1976 landslides removed material from the lower canyon slopes which could tend to make the upper canyon slopes less stable. However, there is no evidence (through September 1999) that large landslides have occurred in the upper canyon slopes in the last two decades since the failure of Teton Dam. Although the upper canyon slopes have been relatively stable during the last two decades, the probability of future localized landslides on the upper canyon slopes (initiated at elevations above the former reservoir level) may have increased because of material removed from the lower canyon slopes.

What effects did the landslides have on rapids and pool formation?

Within the study reach from Felt Dam to Teton Dam, the Teton River canyon is narrowest at the upstream end and tends to become progressively wider in the downstream direction. When

Looking upstream (in order) at pool 12, rapid 12, and pool 11, which are all slightly downstream of Spring Hollow (rapid 9).

landslides naturally occurred in the wider reaches of the Teton River canyon (prior to Teton Dam), the river channel was able to move laterally around the debris fan or incise through the area of finest material, and, consequently, deep pools were not able to persist. In contrast, when landslides occurred in the narrow reaches of the canyon, the river channel was completely blocked, the riverflows were forced to spill over the coarse debris, and persistent, deep pools were formed upstream.

In the 5-mile reach downstream from the confluence with Canyon Creek to the dam site, the landslide debris associated with the filling and rapid drawdown of Teton Reservoir landed on high terraces and typically did not reach the river channel. Therefore, the river channel and its hydraulics were not significantly affected by landslides downstream from Canyon Creek.

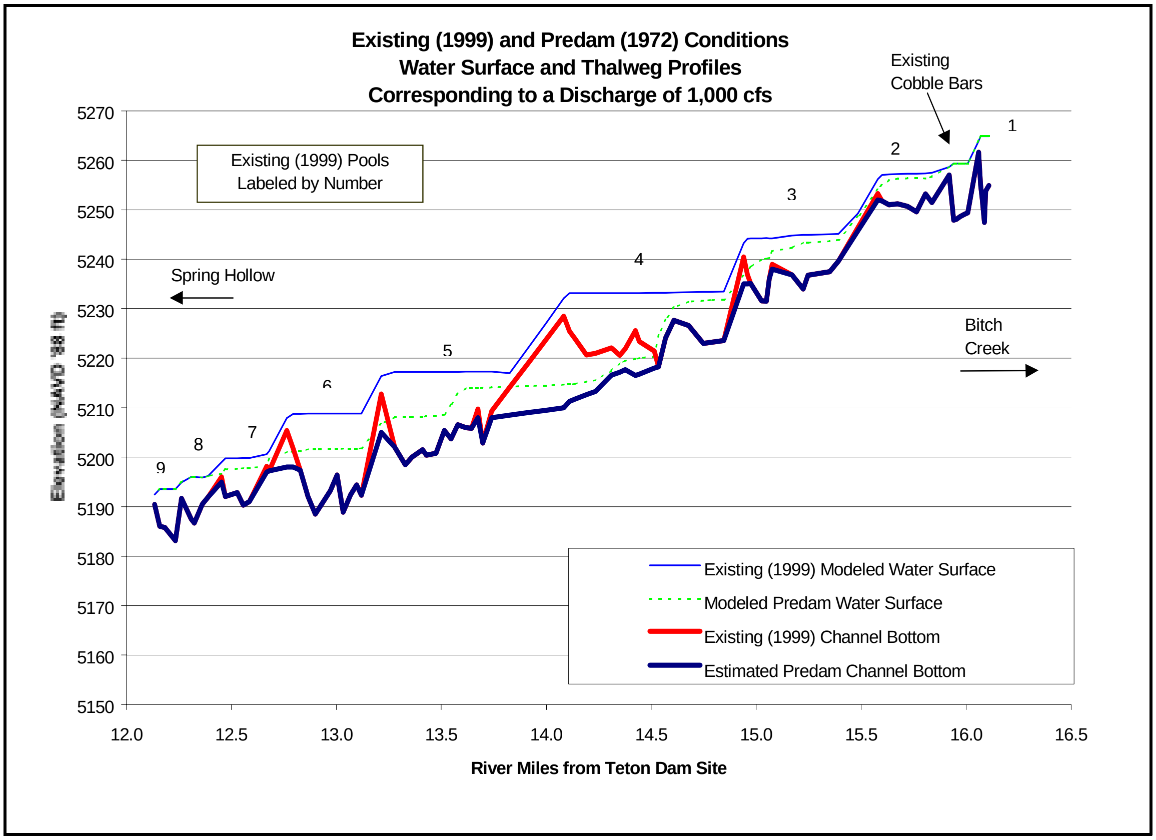
Looking upstream at a site 4 miles upstream from the dam site, where the Teton River has wide flood plains along the north side and landslide debris along the south side.

In the 12 miles upstream from the confluence with Canyon Creek, in the former reservoir area, the Teton River canyon was narrow enough that the landslide debris fans typically reached the river channel. These debris fans formed new rapids in some locations and enlarged pre-existing riffles in other locations. The pre-existing riffles were formed by landslides that occurred centuries ago through natural geologic processes.

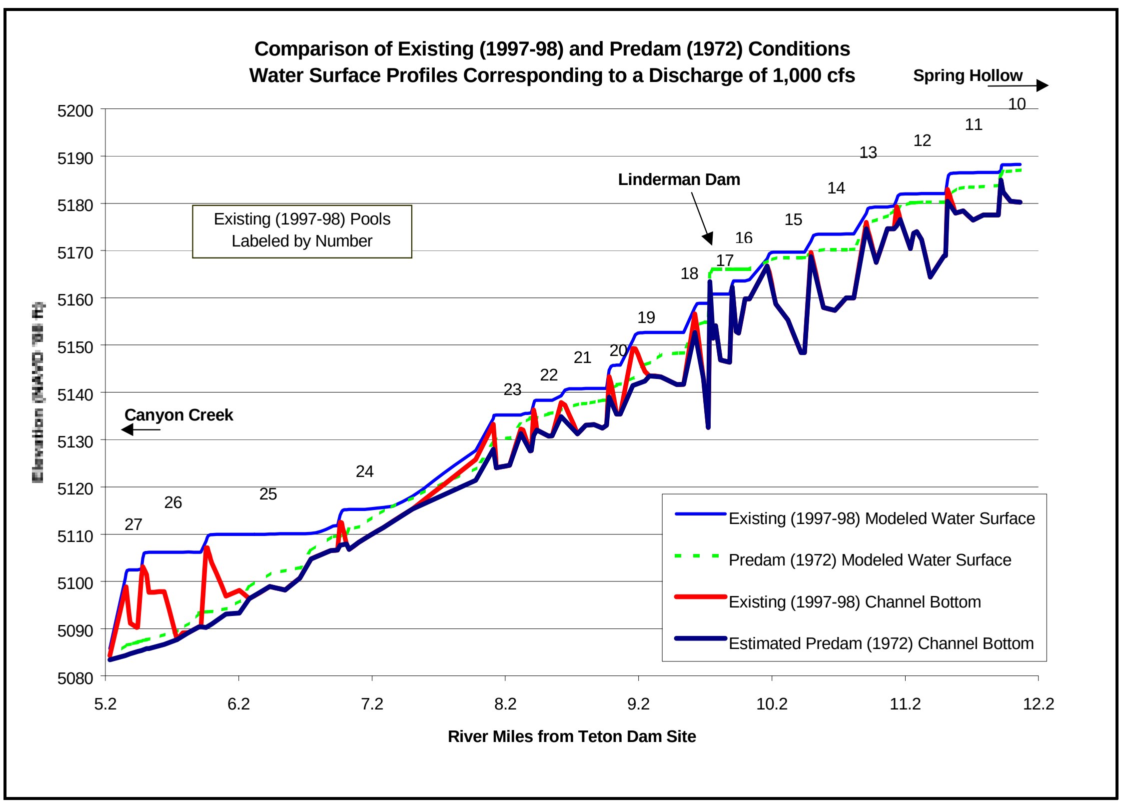
Since the failure of Teton Dam in 1976, 27 rapids and pools have persisted in the reach upstream from Canyon Creek (17 rapids and 1 riffle between pools between Canyon Creek at RM 5 and Spring Hollow at RM 12.1, and 9 rapids and 2 rapid and riffle combinations upstream from Spring Hollow). Landslides also deposited debris in river channel pools upstream from some of these rapids.

Pools are defined for this study as a portion of the river that has a water surface elevation controlled by a downstream feature (such as a riffle or rapid), has a relatively flat water surface with little or no slope, deep depths, and low velocities; and is in the subcritical flow regime. Riffles are defined for this study as a reach of river with high velocities and shallow depths that are in the critical flow regime. Rapids are defined for this study as a reach of river, typically constricted relative to upstream and downstream river widths, that passes through critical depth at the upstream end and creates a large drop in water surface elevation over a short distance. Chutes are defined for this study as a portion of the river containing a series of riffles.

In 1972, two rapids and several small riffles existed between the confluence with Bitch Creek and Spring Hollow. One of these rapids is now inundated by a new rapid formed from the dam



Bitch Creek to Spring Hollow .



Spring Hollow to Canyon Creek.

failure (rapid 1). There were no major rapids present along the Teton River between the Teton Dam site and Spring Hollow (based on inspection of aerial photographs). However, 13 riffles and deep pools existed in the 4-mile reach downstream from Spring Hollow (RM 8 to RM 12). It is estimated that water depths in these pools ranged from 5 to 20 feet. The landslides that occurred in 1976 enlarged many of the existing riffles into rapids and, subsequently, increased pool water surface elevations by 2 to 5 feet (an increase much less than the pool depths). These deep pools measured in 1997 downstream from Spring Hollow must have been present in 1972, because they could not have been created in 1976.

No large landslides occurred in the half-mile reach downstream from RM 8.0, and the river channel was left relatively unaffected by the initial filling of the reservoir and subsequent failure of Teton Dam. The reason that no large landslides occurred in this reach is likely due to the general northeast-southwest orientation of the canyon in this location. Most of the river canyon is generally oriented in an east-west direction so that the south side of the canyon (left side looking downstream) is more shaded, retains more moisture, and develops thicker soil and forest growth than the north (right) side. The north side of the canyon gets more sun and has less moisture; thus, the canyon-wall surface is typically composed of exposed bedrock. Subsequently, nearly all of the large landslides in 1976 occurred on the south side of the canyon. In the half-mile reach downstream from RM 8.0, both sides of the canyon have significant sun exposure, and there was relatively little soil development and forest growth on either side of the canyon. Consequently, the landslides that did occur in this reach were shallow, and the river channel and hydraulics were left relatively unaffected.

Where were the biggest impacts from the landslides?

In the Bitch Creek to Spring Hollow reach, the 1976 landslides had the greatest impact on a 2-mile stretch of river where 3 major rapids now exist, creating a 30.5-foot drop over 3 pools (4, 5, and 6). Pool 4 is the longest of the pools, stretching over 4,000 feet.

In the Spring Hollow to Canyon Creek reach, the 1976 landslides had the greatest impact on the Teton River channel in the 2-mile reach upstream from Canyon Creek. In 1972, there was no evidence of deep pools present. However, there are four new major rapids and pools (24, 25, 26, and 27) in this reach today, with pool depths ranging from 9 to 19 feet. The four landslide rapids in this reach have a total drop of 26 feet over a distance of 2.1 miles.

These rapids and pools must be viewed in sequence. For example, the downstream-most rapid (informally known as Parkinson's Rapid) has the largest single drop in the river in this reach

View of Parkinson's Rapid looking downstream.

(16 feet). The relatively short pool that was formed behind this rapid inundates much of the next rapid upstream (informally known as Little Parkinson's Rapid). If the downstream-most rapid were removed, the next rapid upstream would have an even larger drop than the drop through the existing Parkinson's Rapid.

What are the impacts at Linderman Dam?

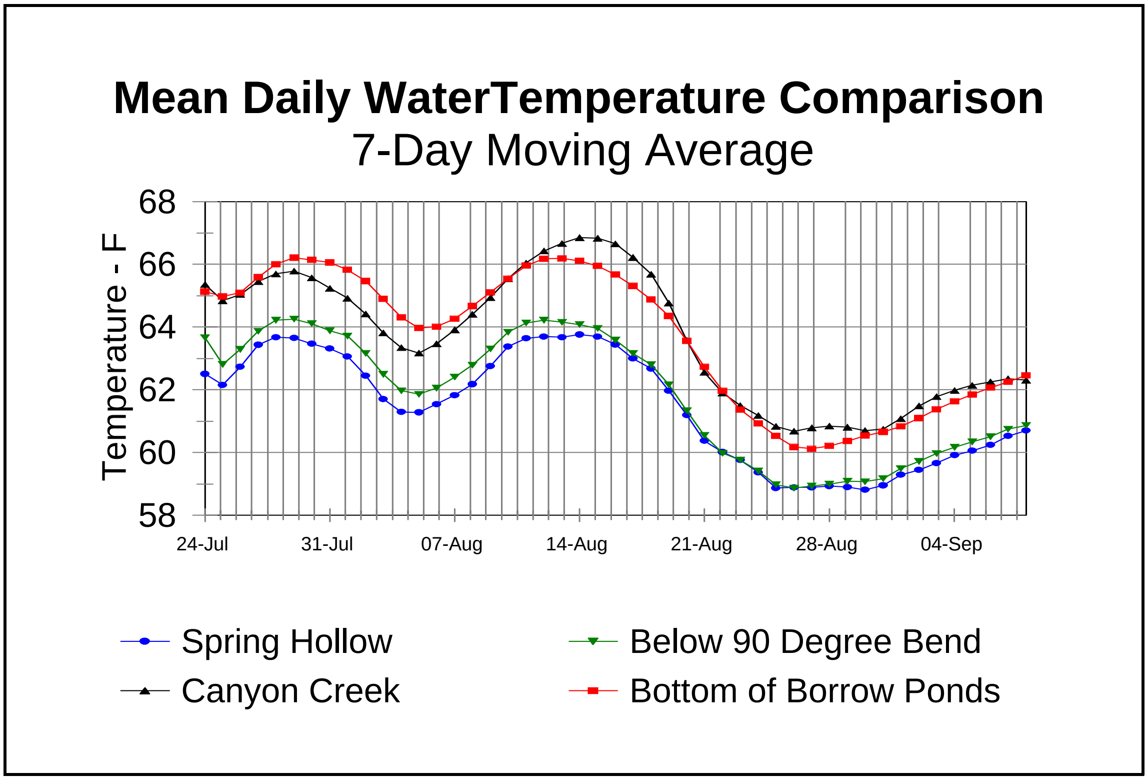
Linderman Dam, at the confluence with Milk Creek (RM 9.7), still has a horizontal concrete beam that extends across a portion of the river at about the level of the water surface (see photograph A-32 in appendix A). At low flow, the water surface is below the bottom edge of the concrete beam, while the beam is at least partially inundated at higher flows. Even though the beam may cover a portion of the water surface at higher flows, the water velocities under the beam are still high, which could create a dangerous undercurrent for boaters. There are also four vertical pipes, evenly spaced across most of the dam's crest, that protrude a few feet out of the water. Although the hydraulic drop across Linderman Dam is now only about 2 feet, the deteriorating condition of the dam (some eroded concrete and exposed metal pipes), the concrete beam that extends across a portion of the river, and the four vertical pipes protruding from the dam's crest pose a safety hazard to boaters and anglers.

View of Linderman Dam looking upstream.

How have the new rapids affected water travel time and temperatures?

Water travel time is the amount of time needed for water to pass through a particular reach of river. The travel time of water flowing through the Teton River canyon from the confluence with Bitch Creek to the confluence with Canyon Creek has increased as a result of the landslide debris fans forming rapids and long, slow-velocity pools in the river channel. At a typical July flow of 1,000 cubic feet per second, the travel time of water has increased from predam conditions by about 6 hours (from 8 to 14 hours). Part of this increase is due to the formation of pools 4, 5, and 6, which have a much higher water surface and deeper depths than in 1972. The other part of this increase is due mainly to the four new large rapids between RM 5.3 and RM 7.4. Travel time of water has not changed in the reach between Canyon Creek and the borrow ponds (RM 1.5 to 5.0).

Water travel times may have significantly increased through the two large borrow ponds near the dam (RM 0.4 to 1.5), but the magnitude is not precisely known. The two borrow ponds combined are just over 1 mile in length, contain a total water volume of 1.6 million cubic yards (1,000 acre-feet), and potentially increase water travel times by up to 12.5 hours. However, flow patterns through the borrow ponds are complex, due to the presence of a side channel which can bypass flow around the lower borrow pond and the potential for horizontal eddy currents, density currents, and vertical recirculating zones within each borrow pond. The slow moving, or nearly stagnant, water near the borrow pond surface would undoubtably be warm during the summer months, but the warm surface water may not necessarily mix with the inflowing river water (which may form a density current) and may not result in a substantial increase in water travel time.



Increased temperature is postulated to result from the increased travel time, and shallow, lower velocity, larger surface area pools resulting from the many small landslides induced by inundation and dam failure that are partially blocking flow. The construction and subsequent failure of Teton Dam has likely increased summer river water temperatures by 1 to 2 degrees Fahrenheit (°F). Temperatures have increased because flows today move slower through the river pools enlarged by 1976 landslides and through the borrow ponds excavated for the construction of Teton Dam. The loss of riparian trees, especially in the reach downstream of Canyon Creek, also would have contributed to increased river temperatures. Suitable temperatures for trout probably still exist in the deeper portions of the borrow ponds and river pools upstream from Canyon Creek. Most of the temperature gain occurs along the reach of river between pool 24 (7-½ miles upstream of Teton Dam) downstream to Canyon Creek and in the borrow ponds.

During the water temperature monitoring period, all of the data loggers recorded at least one or more temperatures above 60 °F. Although the 1- to 2-°F increase in water temperature appears small, the increase could be significant if the natural water temperatures needed by Teton River fish species were already near their threshold. It seems likely that fish can find cooler water temperatures at deeper depths known to exist, but not monitored in this study, as needed during the warmer period of the diurnal cycle. This would suggest that the "lifestyle" of native fish may be affected by forcing them to seek deeper depths during mid- to late afternoon.

How has the Teton River bed material composition changed?

River bed material refers to the types of sediments found along the channel bed of a river. In the former reservoir area, the enlargement and development of the 27 pools from the dam failure has affected the river's capacity to transport sediment. The increase in water travel time found in some of the pools has increased the sediment trap efficiency in those pools. This means that finer-grained sediment particles (i.e., sand, silt, and clay) may settle out along the pool bottom and become part of the channel bed material. The change in bed-material particle size, caused by the 1976 landslides, cannot be precisely determined because there is no predam data available. However, bed-material observations and samples collected in the pools upstream from Canyon Creek were compared with the general characteristics of the channel upstream from pool 1 and downstream from Canyon Creek, which is a gravel-bed river.

Looking downstream from Felt Dam Powerhouse, located about 19 miles upstream from Teton Dam (upstream of the former reservoir area).

Upstream from the former reservoir inundation area, the river channel is extremely steep and narrow. The sediment transport capacity in this reach is presumably high, as a result of the river gradient, narrow widths, and high velocities. Between Bitch Creek and pool 1 (the first pool backed up by a landslide-formed rapid), the river has shallow, uniform depths, and the channel bed primarily consists of 3-inch to 6-foot-diameter boulders.

On the basis of sediments observed along the channel bed, measured pool depths and channel widths, and computed water travel times, pools 1-3 appear to be near the maximum storage capacity for sand, and pool 4 has been the major sediment trap along the river. Eventually, pool 4 will fill in to a maximum storage capacity, and fine-grained sediments will be further transported downstream. Because of its long travel time (over 1 hour), pool 5 will be the next major sediment trap in the river system. The process to nearly fill pool 4 has taken over 20 years and can be expected to take near this amount to fill in pool 5.

The sediment particles along the channel bottom of the pools in the Spring Hollow to Canyon Creek reach are definitely finer than the bed material downstream from Canyon Creek. Silts and clay-sized sediments have deposited along the channel bed in the longer and slower pools. The largest pools (25 and 26) were formed as a result of landslides in 1976 and occurred in a reach (RM 5.5 to RM 6.9) where deep pools were not present in 1972. Therefore, it is likely that the bed material of these pools is much finer today (dominated by sand, silt, and clay) than it was in 1972 (likely dominated by gravel, cobble, and boulder).

Was Canyon Creek affected by the dam failure?

Canyon Creek is, by far, the largest tributary to the study reach. This creek was severely impacted by landslides caused by the dam failure, but the landslide debris has not been modified to the same extent as landslide debris along the Teton River. Canyon Creek is narrower and has a steeper gradient, on average, than the Teton River, but the drainage basin area and discharges are much less than those on the Teton River. Although landslide debris in Canyon Creek is of similar size to debris in the Teton River, the low flows of Canyon Creek are much less capable of moving material. As a result, landslides and their impact on the river channel have been modified much less than those along the Teton River.

Will the river break down the rapids in time?

The debris fans and rapids formed by the 1976 landslides will eventually be eroded by riverflows, but this process could take centuries. Since 1976, the finer-grained material in the debris fans has been reworked by riverflows, but the coarsest material was left behind, and the rapids and pools are still present. The snowmelt runoff of 1997 produced the largest flood peak since 1976 and was approximately equal to the 100-year flood. Even this large magnitude flood was only capable of minor reworking of the debris forming each rapid. Therefore, the existing rapids are most likely too large to be eroded by a single flood, and the river will take centuries of abrasion and weathering to erode the rapids. This, of course, reflects the rates of natural processes which have been occurring for many thousands of years.

A view of rapid 26, which was formed from landslide material that moved into the river from the north canyon wall.